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Procedia Engineering 113 (2015) 402 – 407

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Oil and Gas Engineering, OGE-2015

Dampener resource of seismic isolation absorber system of circular tanks for liquid hydrocarbons storage

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Abstract

The aim is to estimate fatigue resources of rubber-metal dampener, a part of the seismic isolation of spherical tanks for liquid hydrocarbons storage based on the calculation of the damage measure packages using modern finite element analysis, in particular, ANSYS. Thus performed:

- The calculation of the stress-strain state of the dampener during deformation.
- The fatigue curve of the tested dampener.
- Total measure of the dampener damage during operation was determined.

An example of the proposed method application indicating the ability to provide the required resources of rubber-metal dampener in operation in the seismic isolation spherical tanks system is determined.

Peer-review under responsibility of the Omsk State Technical University

Keywords: rubber steel dampener; stress-strain state, the measure of damage; fatigue curve

1. Introduction

Currently, under the operation structures analysis in addition to the stress-strain state study, assessment of the resources is urgent. And to study questions for the calculation of the resource design two approaches are considered:

- Defects development modelling in this structural element [1, 2].
- Assessment of damage degree to the material in the structure elements provided that the defects and their growth were not considered [3].

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Peer-review under responsibility of the Omsk State Technical University
doi:10.1016/j.proeng.2015.07.304

The first approach is individual for each specific task and requires the development of its own software.The second approach does not estimate explicitly the time of the structure destruction and get the clear picture of the structural damage degree on the basis of the damage accumulation models.Among the destruction processes of one of the most common causes of structures failures is the process cycle fatigue, which is characterized by the absence of macroscopic deformation and loading time of 10^4...10^7cycles.

The paper realized the possibility of rubber-metal dampener research to determine the extent of the material (solid rubber) damage during high cycle fatigue with the use of finite element system ANSYS.At the same time we use the second approach to the study of the structural failure processes with the following circumstances:

- the damage accumulation that leads to the dampener destruction (damage)is localized in a small area, its size is much smaller than the characteristic dimensions of the finite elements;
- the process of destruction does not change the geometric dimensions of the dampener design.

The task of evaluating of rubber-metal dampener damage was determined, being the part of the seismic isolation of spherical tanks, for a given model of operation with sophisticated packet of finite element analysis, in particular, ANSYS.

2. Study subject

The study subject is the rubber metal dampener(Fig .1),it consistsof two metal plates (st.1) vulcanised to rubber blocks (st.2).The mechanical characteristics of the dampener materials are shown in Table 1.Model dampener operation is shown in Table 2.

Table 1. Mechanical properties of dampener materials.

Characteristics	Rubber	Metal
The modulus of elasticity E, Pa	$6{,}2\cdot10^{6}$	$2{,}0\cdot10^{11}$
The shear modulus G, Pa	$2{,}07\cdot10^{6}$	$6{,}6\cdot10^{10}$
Poisson's ratio, μ	0,49	0,32
Ultimate stressσ_{in}Pa	$1{,}4\cdot10^{7}$	$4{,}2\cdot10^{7}$
Density ρ, kg/m^3	1200	7850

Table 2. Availability model of the dampener.

Loading block	The displacement amplitude, mm	Number of cycles
1	± 4,50	$1{,}5\cdot10^{5}$
2	± 0,03	$14{,}5\cdot10^{6}$
3	± 0,30	$12{,}0\cdot10^{6}$

3. Methods

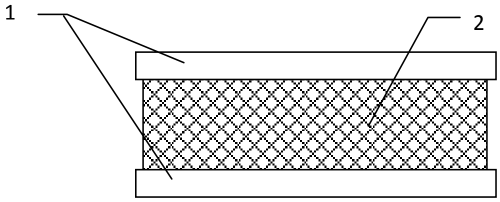
In solving the problem of fatigue resources estimation of the dampener the following basic steps [4] were completed:

- Construction of finite element model.
- The calculation of the stress state of the dampener of the load history.
- Determining the critical point (zone) of the dampener.
- Determination of the load history.
- Setting the dampener characteristics of the material.
- The calculation of the damage measure for the dampener.

Let us examine every stage.

1) Creation of a finite element model

To calculate the package of finite element analysis it is required to construct a finite element model of the object of study.So firstly, volume three-dimensional model of the object is constructed, and then it is divided with the standard software for finite elements. The method of dividing and type of finite elements are selected depending on the structure of the object of study and the problem setting.Dampener model is presented with uniform grid of three-dimensional elements eight-node type Solid.



1 – metal plates; 2- rubber solid

Fig. 1. Rubber-metal dampener.

2) The calculation of the stress state of the dampener from the load history

The damage accumulation occurs by the action of the dampener under time-varying loads, which are described by the model operation.To determine the impact degree on the dampener with operating shock loads their stress-strain state is calculated.For the purpose, a finite element model of the object of study is consistently applied loads according to the model of operation, and every stage of a static analysis. The result of this calculation is the volume distribution diagrams of stresses and strains, which are then used to determine the fatigue recourses in the module Fatigue.

3) Determination of the critical point

The calculation of stress-strain state is determined by a critical point, as the most loaded zone of the dampener design.

Multicycle fatigue refers to the destruction process, localized near the critical point (zone), where there are the most favourable conditions for its development.The point is determined by the stress-strain state of the dampener and its structural characteristics.

4) Determination of the load history

The structural elements in the operation mainly have multiaxial stress state .Most of the experimental data to base the calculation of fatigue recourses were obtained due to uniaxial loading at symmetrical cycle. Therefore, prior to the calculation of the damage measure dampener schematization load history is conducted, bringing the history from to the random loading to regular block loading of [5].In addition, one should go from the multiaxial stress state to uniaxial and from asymmetric to symmetric loading cycle.

To move from a multi-axis to uniaxial stress state there are used different types of damage to the equivalent voltage.When switching from asymmetrical to symmetrical voltage cycle various types of equivalent strain are used.The result of the process and the schematic information to the equivalent value of the load history is a sequence of values of the equivalent voltage amplitude under uniaxial symmetric loading cycle σ_{a_e} determined from the following expression [6]:

$$\sigma_{a_e} = \sigma_a + \psi_\sigma \sigma_m \tag{1}$$

where σ_a, σ_m is peak and average voltage value of asymmetric loading cycle; ψ_σ is stress ratio of the cycle.

5) The total calculation of the damage to the dampener action

Let us assume that each loading cycle in the process of destruction of the dampener is repeated k times. For a description of the damage accumulated in the dampener, the most widely used rule of linear summation of damage by Palmgren-Miner, and according to it the damage accumulated in a critical point is determined by the formula [7]:

$$D_i = \frac{k_i}{N_i} \quad (2)$$

where k_i is the repetitions number of the amplitude $\sigma^i_{a_e}$ during loading;

N_i is the number of cycles to failure at the amplitude of the voltage σ_{a_e} determined by the Wohler curve.

Damage accumulated in a critical point of the dampener for given loading conditions will be equal to

$$D_\Sigma = \sum_{i=1}^{n} D_i = \sum_{i=1}^{n} \frac{k_i}{N_i} \quad (3)$$

The condition of destruction (damage) of the dampener is:

$D_\Sigma \geq a_p$, *where* $a_p \geq 1.1$.(4)

4. Results and discussion

In the course of the investigations all phases of work on the definition of fatigue resources of rubber-metal dampener are consistently determined.According to the results of tests of rubber-metal dampener samples Wohler fatigue curvewasmade (Fig. 2).For the calculation of the stress-strain state of the dampener system ANSYS finite element model is designed with interpolate 6480 hexagonal and 4-node elements(Fig. 3).As the most heavily loaded point there was selected unit №1280isolated on a volume Mises stress distributionwhen compressive deformation of 4.5 mm(Fig 4).

Here are the results of calculation of damage to the dampener volumes.

```
PERFORM FATIGUE CALCULATION AT LOCATION   0   NODE      1280
        *** POST1 FATIGUE CALCULATION ***
    LOCATION   1  NODE   1280
 EVENT/LOADS   1   1                    AND   1   2
  PRODUCE ALTERNATING SI (SALT) =  0.16866E+07 WITH TEMP =   0.0000
  CYCLES USED/ALLOWED = 0.1500E+06/ 0.3916E+07 = PARTIAL USAGE =   0.03830
 EVENT/LOADS   3   1                    AND   3   2
  PRODUCE ALTERNATING SI (SALT) =  0.11244E+06 WITH TEMP =   0.0000
  CYCLES USED/ALLOWED = 0.1200E+08/ 0.8511E+08 = PARTIAL USAGE =   0.14099
 EVENT/LOADS   2   1                    AND   2   2
  PRODUCE ALTERNATING SI (SALT) =   11244.     WITH TEMP =   0.0000
  CYCLES USED/ALLOWED = 0.1450E+08/ 0.8511E+08 = PARTIAL USAGE =   0.17036
 CUMULATIVE FATIGUE USAGE =    0.34965
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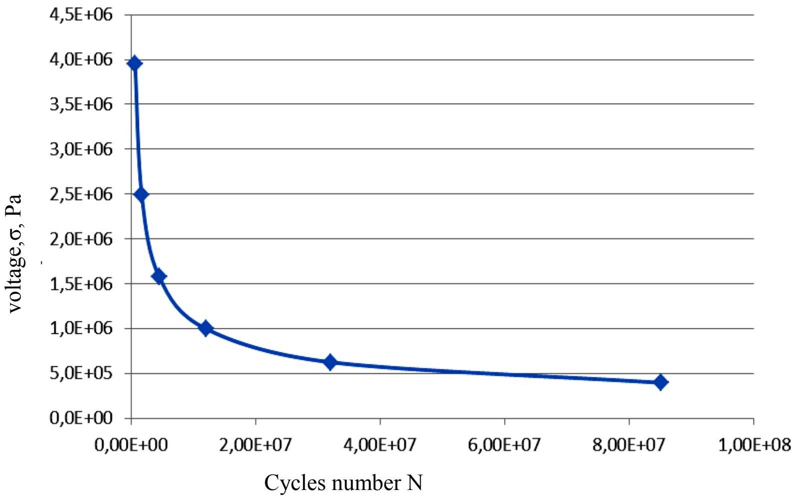

Fig. 2. Fatigue curve of rubber-metal dampener.

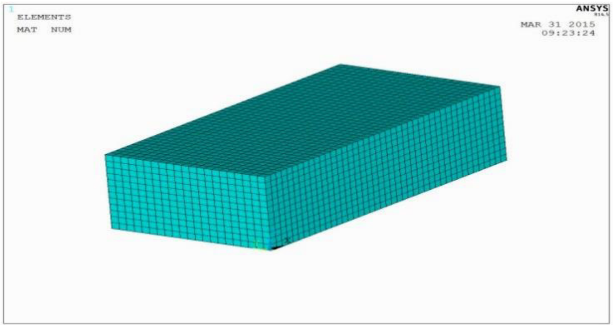

Fig. 3. Finite-element model of the dampener.

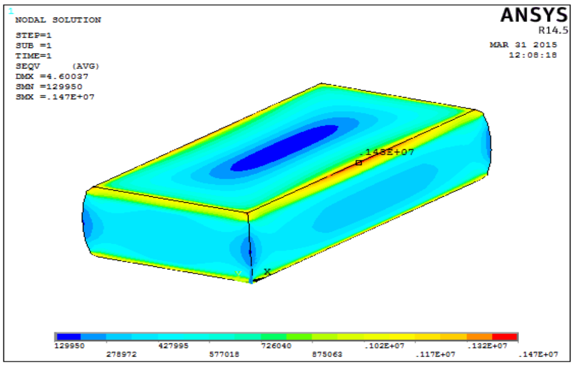

Fig. 4. Volume diagram of Mises stress distribution while 4.5mm deformation with the most loaded node.

Thus, the result obtained by calculating the total measure of damage to the dampener amounted toD_{Σ}=0.34965.In accordance with the fact that the total measure of the damage does not exceed unity, we can conclude that the analyzeddampener belongs to the seismic isolation system of spherical tanks provides fatigue resources for a given operating pattern.

5. Conclusion

In the research course aimed at studying the fatigue resources of rubber-metal dampeners that are included into seismic spherical tanks for storing liquids, it was calculated the total measure of damages for a given operation model.The calculations of the stress-strain state of shock and fatigue resources were completed with advanced packet finite element analysis ANSYS.Considered in the example of application the proposed method shows the possibility of providing the required resource of rubber-metal dampener in operation in the system of seismic isolation spherical tank.

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